COMMUNICATIONS ANALYSIS GRAPHICAL ENVIRONMENT (CAGE): A SIMULATION TOOL THAT CAN ANALYZE KA-BAND COMMUNICATION SYSTEMS PERFORMANCE IN THE PRESENCE OF INTERFERENCE AND RAIN ATTENUATION

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1. INTRODUCTION

Communications Analysis Graphical Environment (CAGE) is a Personal Computer (PC) based software tool that is used to design and analyze communication systems. CAGE can determine the communications performance of any network in the presence of interference, atmospherics, multipath, and blockage. It is ideally suited for assessing the performance any communication system operating in the Ka-band. First, CAGE can model all the different type of systems which utilize this band, such as the Fixed Service (FS), Fixed Satellite Service (FSS), Mobile Service (MS), Mobile Satellite Service (MSS), and Inter-Satellite Services (ISS). Secondly, it can include degradations due to interference and rain attenuation, which can be quite significant at Ka-band.

CAGE utilizes a menu driven, graphical block diagram editor that allows users to configure a hierarchical communication system using a large selection of standard library blocks, functions, and outputs. The results are displayed graphically on the computer screen while the program simulates the system. At the completion of the simulation, the results are stored in a file. The main feature of CAGE is its versatility; CAGE can run any type of static or dynamic simulation because it allows users to easily define their own variables and equations. For example, a CAGE system can simulate many terrestrial FS stations and several different satellite systems and calculate interference statistics due to the emissions of all interference sources. Alternatively, the simulation can calculate view periods, look angles, and bit error rates, even when a spacecraft is experiencing solar interference, being launched, switching its antennas, tumbling, or reacting to an emergency situation. CAGE also allows the user to interactively point a spacecraft antenna, open cargo bay doors, rotate a solar panel, or tumble the spacecraft during the simulation, and then watch the effect in a 3-D display, timeline, and histogram. With all the versatility provided by CAGE, users can easily evaluate different "what-if" scenarios without ever having to develop or modify existing code.

This paper describes the features, capabilities, and applications of CAGE in designing and assessing Ka-band systems. As an example, it presents how CAGE was used to assess interference statistics to Tracking Data Relay Satellite System (TDRSS) Ka-band forward Space-to-Space Links from the Iridium Inter-Satellite Links (ISLs).

Section 2 identifies some CAGE features useful in configuring systems. Section 3 describes how to run a simulation and how the results are displayed. Section 4 shows an example of how CAGE is used to calculate interference statistics for TDRSS forward ISLs from the Iridium network. Section 5 defines the PC system requirements. Section 6 compares CAGE to other similar software programs. Section 7 describes the CAGE development background and discusses how to obtain additional information.

2. FEATURES OF CAGE SYSTEM CONFIGURATIONS

2.1. INTRODUCTION

The user develops the communication system using the graphical block diagram editor, the menu bar, and the mouse. The user places sources in the system by selecting them from a library or by adding a completely new source. The user defines the configuration of each source by clicking down into the source and deleting and adding ports, deleting and adding variables, and by defining variables according to equations. Ports and their associated links allow users to define the data in each source that is available for use by other sources in the system. Equations can be developed using standard functions and conditional IF-THEN-ELSE statements. CAGE standard functions include routines that calculate: circular and elliptical orbits, the antenna gain at a given angle for standard ITU antenna patterns , free-space loss, atmospheric loss, and distance between two sources. There is also a function that calculates the composite interference level from all interference sources in the system. For each visible interference source, this function first calculates the angle between the transmitting antenna boresight and the receiving station, and the angle between the receiving antenna boresight and the transmitting station. It then calculates the interference from each visible source as the sum of the transmitter power spectral density, the transmitter antenna gain in the direction of the receiver, the free-space loss, and the receiver antenna gain in the direction of the transmitter. Finally, the function returns the sum of the interference received from each contributing source. This function also has an option that not only accounts for direct path interference, but it can also account for multipath due to reflections off of planets.

Figure 1 shows the graphical user interface with an example where the user has five sources in the CAGE system. One source represents the Iridium mobile satellite system, another source the East Tracking and Data Relay Satellite (TDRS), another the West TDRS, and a fourth source represents a Low Earth Orbiting (LEO) user spacecraft. The Earth is also represented as a source because these four sources are defined as orbiting the Earth. The motion of each satellite system is defined simply by linking the orbit port to the Earth, which is a standard library block, and using the standard orbit generator function. Once the orbital elements have been entered, CAGE has enough information to simulate the motion of all satellites in the system. Since the orbit port is linked to the Earth, the orbit generator function obtains information, such as the mass and rate of rotation, from the Earth block. However, the user is not constrained to have all satellites orbit the Earth. A user can also configure a system where the Earth is orbiting the sun, the moon is orbiting the Earth, a satellite is orbiting the moon, and the satellite is tracking a comet. The location of the comet can be defined according to a rule-based scheduling algorithm or a data file.

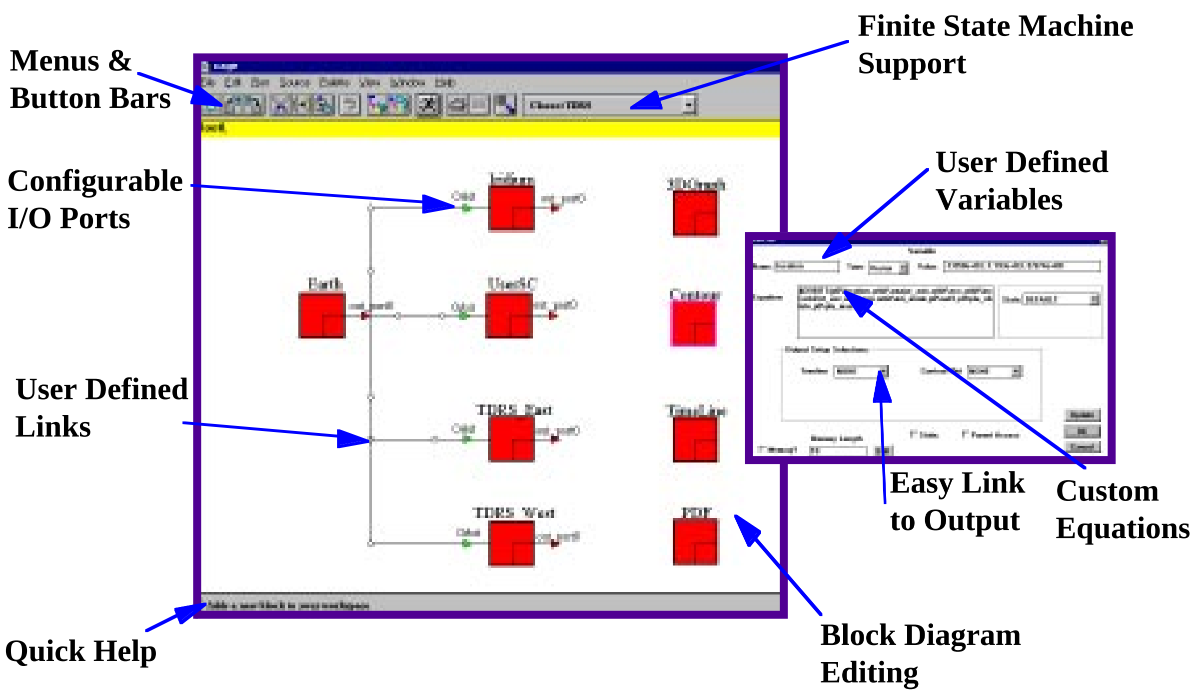

Figure 1. CAGE Graphical User Interface

2.2. BATCH SOURCES

CAGE also supports batch generation of similar sources, which is very useful in modeling MSS, FSS, or FS systems. A batch source allows the user to configure the system parameters that are common for the whole network in the main source, and define the parameters that are unique for each element separately. For example, the Iridium satellite system has the same altitude, inclination angle, transmission frequency, transmitter power spectral density, and antenna pattern on each satellite. However, each satellite has a different Right Ascension of the Ascending Node (RAAN), Mean Anomaly (MA), and antenna pointing vector. The variables that are common to the whole system are defined as a fixed value. The variables that are unique to each element can be defined either by an equation in the main source, or uniquely in each element. CAGE generates all the elements in the batch. For example, the Iridium satellite system was modeled as a batch source with 6 planes and 11 satellites per plane. The RAAN, MA and antenna pointing vectors were set according to equations. When the user exercises the "generate source" option in the main menu, CAGE automatically generates 66 satellites in the appropriate orbit with the correct antenna pointing vectors. It is not necessary to modify any of the elements of the Iridium satellite network, but each source can be individually modified if desired. The batch source feature is also useful in defining terrestrial FS networks in different cities with trendlines at various angles as described in [1] and [2].

2.3. STATE MACHINES

CAGE also supports finite state machines. As a simple example, a state machine with two states can be used to define when the LEO spacecraft is communicating with the TDRS-East or TDRS-West. When the LEO spacecraft is closest to TDRS-East, it is assumed to communicate with TDRS-East and when it is closest to

TDRS-West, it is assumed to communicate with TDRS-West. The user can configure CAGE to select the appropriate state based on the LEO spacecraft position and then point the user's antenna appropriately. Actually this example is so simple that the user can define the LEO spacecraft antenna pointing vector with a conditional If-Then-Else statement. However, CAGE is flexible enough to handle much more complex state machines. For example, a complex state machine can model spacecraft communications with a ground network that contains many ground stations.

2.4. BUILT-IN ERROR CHECKING

The block diagram editor contains built-in error checking. For example, the user is provided with error messages if the user tries to connect ports of different types, calls a standard function with an invalid parameter, or calls a standard function with the wrong number of parameters.

2.5. OUTPUT

CAGE provides output in the form of timelines, histograms, Probability Density Functions (PDFs), Cumulative Density Functions (CDFs), contour plots, and dynamic 3-D displays. 3-D displays can be used to show the satellite systems' orbit trajectory, antenna pointing vectors movement with the satellite, antenna beam projections onto the earth or in space, and 3-D antenna patterns. Users select the types of output that they need by placing the appropriate output block in the system. They link each variable that must be saved and/or displayed to the appropriate type of output. For example, if the user wants to generate the results shown in Figure 2, the user links the satellites' location to the 3-D output block and contour plot output block. The user also links the interference power received to the timeline output block and histogram output block. The results can be displayed graphically during the simulation and/or stored in a file.

CAGE can support any user defined 3-D model. CLASS personnel can assist with converting users 3-D models to be compatible with CAGE.

2.6 INTERACTIVE SIMULATION CONTROL

CAGE allows users to interactively control the simulation and view the results in real-time. For example, the user can control the extent to which the Shuttle cargo bay doors are opened with the dynamic model controls shown in Figure 2. At the start of the simulation, the user can close the doors by placing the control button to the far left. At any point during the simulation, the user can open the doors by any amount by dragging the control button to the right. The more that the button is dragged to the right, the more that the doors are opened. Since the simulation is interactively controlled in real-time and the results are displayed in real-time, the user can immediately observe the effects of this action on the received interference power level. The user can also interactively control the appearance of the 3-D display by controlling, for example, the camera zoom, roll, pitch, and yaw as shown in Figure 2. Interactive simulation controls can be used to set any variable in the system, not just variables that control the graphics display. For example, the user can set an interactive simulation control for the transmitter power level.

3. RUNNING A SIMULATION

The user controls how CAGE simulates the system. For example, the user can run a simulation for x number of samples with a time increment of y seconds between samples. However, the user can also define a simulation with x number of samples and set the time for each sample to be a random variable. This can be useful in gathering interference statistics on systems where interference levels change slowly most of the time, but can change quickly during special situations, such as mainbeam-to-mainbeam interference. It may be possible to reduce the number of simulation points required to gather interference statistics by setting the time to be a random variable, rather than directly incrementing time in the simulation.

The user starts a simulation simply by clicking on the runner figure in the block diagram editor menu bar. If there are any simulation errors, the program reports them to the user. Otherwise, while the simulation progresses, the screen shows the results that were selected for display and it is continously updated in real-time.

4. IRIDIUM EXAMPLE

The Iridium ISLs operate in the same band as TDRS-to-LEO forward Space-to-Space Links (SSLs). Iridium ISL emissions will appear as an increase in the received noise level at the TDRSS LEO. CAGE was used to assess the interference statistics for for the forward SSL signal due to the Iridium ISL emissions. The TDRSS LEO spacecraft was assumed to be in a 407 km altitude orbit with a 98.6˚ inclination angle. The Iridium satellite system was modeled with 66 satellites in a 780 km altitude orbit and an 86.5˚ inclination angle. The satellites were in six planes that were separated by a RAAN of 31.6˚. The 11 satellites in each plane were spaced apart by a MA of 32.73˚. The MA for satellites in adjacent planes were offset by 16.36˚. Because the Iridium satellite system uses 8 transmission frequencies within the TDRSS band, and each satellite transmits on four frequencies, the simulation was modeled with one-half of the Iridium satellites transmitting to the satellite ahead of it in the next plane. (Satellites in the 6^{th} plane can not transmit to the 1^{st} plane since the satellites in these planes go in opposite direction. Therefore, it was assumed that all the satellites in planes 1, 3, and 5 transmit the ISL and all the satellites in planes 2, 4, and 6 receive the ISL.) The simulation assumed that each satellite transmits a Power Spectral Density (PSD) of -68.9 dBW/Hz. It also assumed that the Iridium satellite

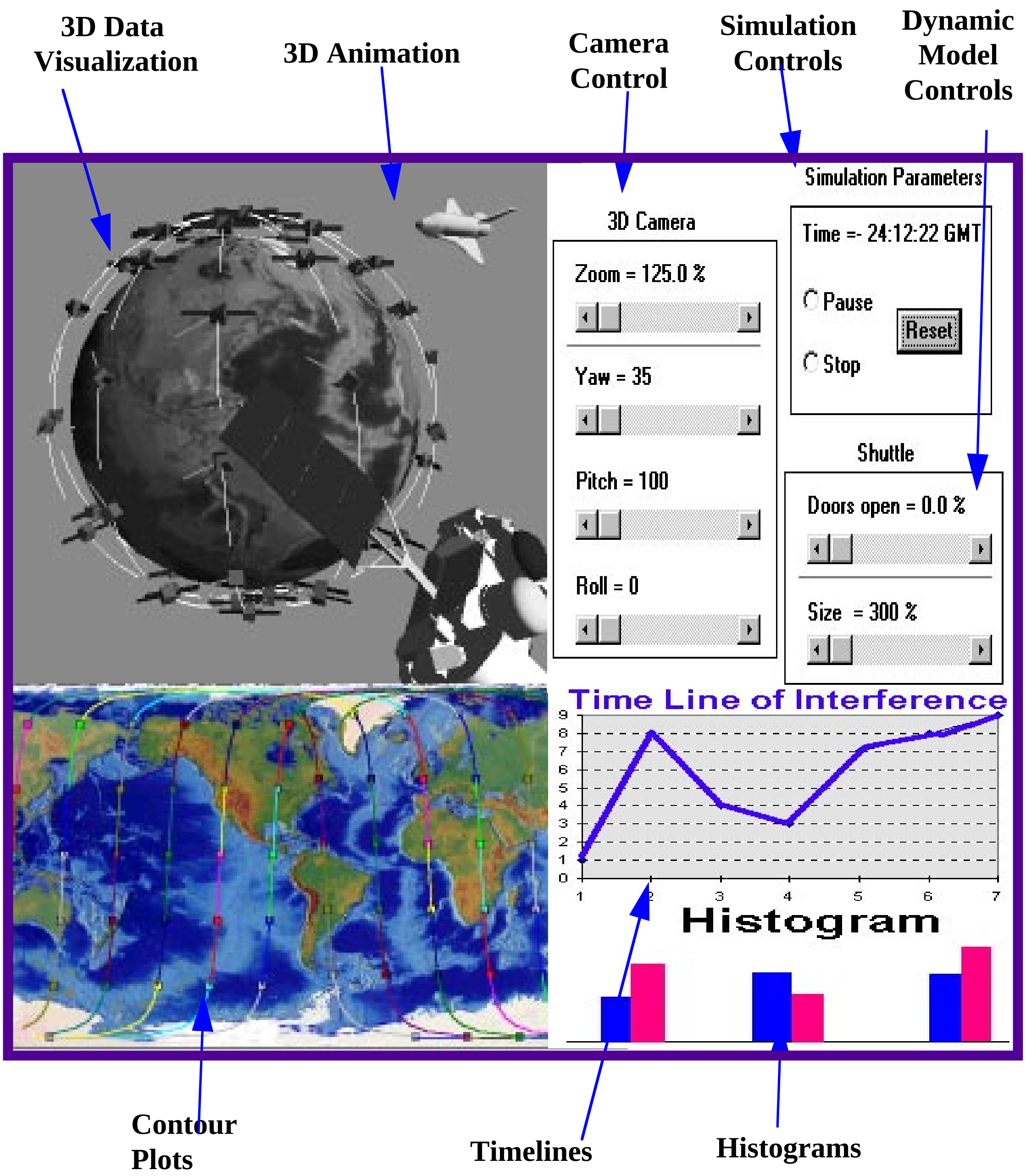

Figure 2. CAGE Graphical Display of Simulation Results

antenna has a boresight gain of 36.7 dBi and conforms with the reference pattern in the ITU Radio Regulations, Appendix 29. The TDRSS LEO was assumed to have a boresight gain of 46.1 dBi and conforms to the reference pattern in Recommendation 672 [3].

The simulation was run for 100,000 samples with the time of each sample selected randomly. It was completed within 4 hours on a PC containing a Pentium processor with a 133 MHz clock speed. The simulation results are shown in Figure 3. Also shown in the figure is the interference PSD criteria of -148 dBW/MHz, 0.1% of the time provided in ITU-R SA.1155 [4]. This figure shows that interference to the TDRSS LEO from the Iridium satellite system does not exceed the interference criteria. The results in this figure are consistent with results provided in [5].

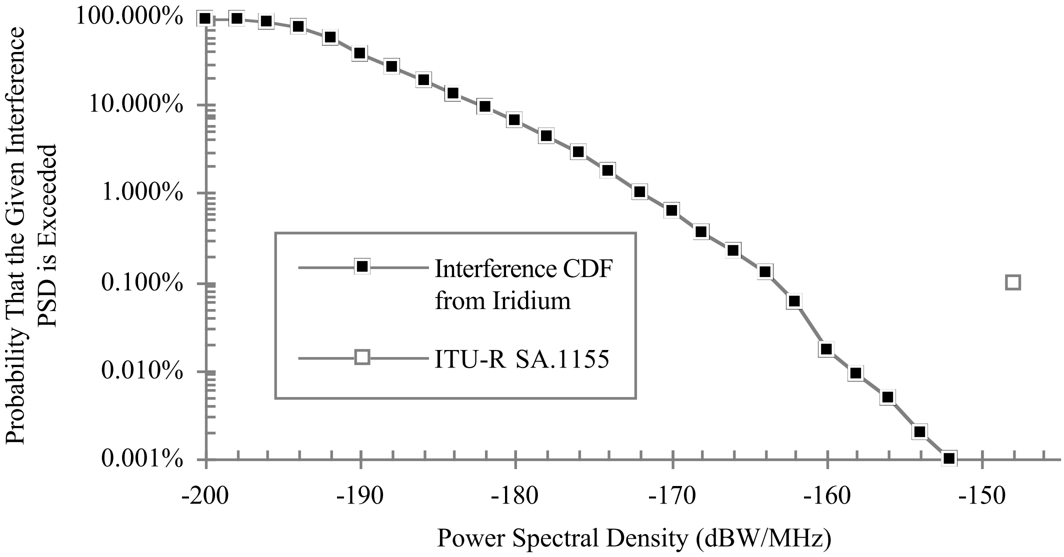

Figure 3. Sample Result: Interference Statistics at the TDRSS LEO (700 km altitude, 98.2° inclination) from Iridium Inter-satellite Emissions

5. SYSTEM REQUIREMENTS

CAGE can be used on any IBM compatible PC while running Windows 95 or Windows NT. A 486 processor with a 25 MHz clock speed is the minimum recommended for most applications. However, a Pentium processor with a 90 MHz clock speed is recommended for 3-D graphics and/or long simulations.

6. SIMULATION TOOLS COMPARISON

The two most popular software tools available to assess communication system performance are Signal Processing Workstation (SPW) and Satellite Tool Kit (STK). Like CAGE, SPW allows users to build a communication system with standard library blocks, run the simulation, and view the results graphically. SPW has an extensive library of communications blocks and can simulate many types of static simulations. SPW can also simulate some dynamic simulations, such as the effect of fading or multipath. However, CAGE is much more versatile and powerful than SPW in simulating dynamic situations. For example, SPW does not display 3-D graphics. It also can not calculate interference statistics between satellite systems and between satellite systems and terrestrial FS networks, whereas CAGE can easily perform this simulation.

STK is a simulator and graphics tool for analyzing and visualizing satellite systems, such as satellite orbits, attitude maneuvers, sensor field of view, and ground station coverage. However, the STK does not have nearly as much communication systems performance analysis capability as CAGE. For example, STK can not calculate BERs or interference statistics, and it can not model multipath. Clearly, CAGE is the most powerful and versatile software tool available on the market for assessing the performance of communication systems in a dynamic environment.

7. CAGE SYSTEM BACKGROUND

CAGE was developed by the NASA/GSFC Communications Link Analysis Simulation Systems (CLASS) project. The CLASS project team is a dedicated and highly skilled group of communications and software engineers from NASA and STel that have been providing systems analysis, support services, and powerful resources for space flight projects and NASA's space and ground networks since 1978. In order to adapt to the dynamic needs of the space community, the project team has developed a comprehensive and flexible suite of analytical software tools. STel, under contract to NASA/GSFC, develops and maintains these software tools, customizes them as needed for customer applications, and provides communications analysis services. STel is also a proven leader in the field of communications and has been developing and manufacturing communications products, developing and maintaining software tools, and providing systems engineering services for military and commercial customers for more than 20 years.

NASA is teaming with STel to market CAGE and all the other CLASS tools. CAGE is expected to be available for retail sale from STel by the first quarter of 1997. STel will support the release of CAGE by providing installation, training, maintenance, and customer support services. Customer support services can include RF communication systems design and analysis, mission operations support, and custom software development. Information about CAGE can be obtained from the NASA and STel CLASS project managers at the above addresses.

9. REFERENCES

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